WARM WATER AQUACULTURE USING WASTE HEAT AND WATER FROM ZERO DISCHARGE POWER PLANTS IN THE GREAT BASIN

Richard A. Heckmann[1], Robert N. Winget[1], Rex C. Infanger[1],
Roger W. Mickelsen[1], and John M. Hendersen[1]

Abstract.— Two series of experiments were completed to determine (a) toxicity of waste water from power plants on warm water fish and (b) multiple use of waste heat and water for aquatic animal and plant production. All three types of waste water from a typical coal-fired power plant are acceptable for growing catfish and tilapia following aeration. This growth was compared with fish raised in spring water. Closed, recirculating polyculture systems using evaporation pond water operated efficiently for plant (duckweed) and animal (fish and freshwater prawns) production. Duckweed is an excellent supplement for fish feed. Tilapia and freshwater prawns grew rapidly in the tanks containing duckweed only.

Efficient use of natural resources will be essential in the next decade, especially as it relates to energy reserves. The lower sulfur coal reserves of the western United States are large and are expected to be used as an energy source for many years to come. Design of coal-fired power plants has improved so that more electricity can be produced with minimal impact on the environment. However, plant operation still depends on the availability of large quantities of high-quality water. Although plant efficiency has improved, massive amounts of waste heat is produced and expelled via water-cooling systems. The wasted heat is generally of little use to industry but could be used for warm water aquaculture (Table 1).

Aquaculture involves the farming of economically important species of fish and shellfish (Holden 1978). Aquatic animals tend to have better feed conversion ratios than terrestrial animals, because aquatic animals expend only minimal amounts of energy supporting body weight and in maintaining a constant body temperature.

Development of aquaculture facilities utilizing the tremendous amounts of waste heat produced by power plants should be a goal for maximum use of the coal reserves for the western states. One objective of our research for the past four years has been the development of multiple-use aquaculture systems for the waste heat from power plants in Utah.

Observations of the evaporation ponds at both the Hunter and Huntington power plants in Utah have indicated that at certain times the ponds contain abundant plants and animals and at other times aquatic life is absent. It appears from these observations that a toxin or low dissolved oxygen levels could be responsible for the periodic mortality. These observations led to the initial experimentation to determine probable reasons for this mortality.

It was found in a pilot study that evaporation pond water from the Huntington power plant on occasions was lethal to fish. This

Table 1. Potential uses of thermal waters (adapted from Rinehart 1980).

Degrees (C)	Use
20	Hatching of fish, fish farming
30	Swimming pools, biodegradation, fermentations, de-icing
40	Soil warming
50	Mushroom growing
60	Animal husbandry, greenhouses by combined space and hotbed heating
70	Refrigeration (lower temperature limit)
80	Space heating, greenhouses
90	Drying of stock fish, intense de-icing operations
100	Drying of organic materials, seaweed, grass, vegetables
110	Drying and curing of light aggregate cement slabs
120	Freshwater by distillation, most multiple-effect evaporators, concentration of saline solutions

---

[1] Department of Zoology, Brigham Young University, Provo, Utah 84602.

TABLE 2. Growth data for long-term toxicity tests. There were 15 catfish and 15 tilapia used in each tank.

Water and animal	Filter system	Initial °WG (gm)	(Ave) L (cm)	40-day WG (gm)	(Ave) L (cm)	60-day WG (gm)	(Ave) L (cm)
COOLING TOWER WATER							
Tilapia	Oyster shell	4.6	4.9	9.9	6.4	19.1	7.98
Catfish	Oyster shell	0.4	2.9	1.3	4.4	3.0	5.9
Tilapia	Bio-ring	5.0	4.5	13.8	7.5	22.6	8.73
EVAPORATION POND WATER							
Tilapia	Oyster shell	4.9	4.7	9.8	6.4	16.6	7.73
Catfish	Oyster shell	0.5	3.0	1.5	4.5	3.3	6.1
Tilapia	Bio-ring	5.5	5.2	12.5	7.0	19.9	8.1
WASTE WATER							
Tilapia	Oyster shell	4.9	4.1	6.4	5.9	12.3	7.1
Catfish	Oyster shell	0.4	3.0	1.8	4.5	3.1	6.2
Tilapia	Bio-ring	4.6	4.6	10.1	6.7	16.5	7.8
SPRING WATER							
Tilapia	Oyster shell	4.6	4.9	8.0	6.2	15.4	7.6
Catfish	Oyster shell	0.4	2.9	1.7	4.9	4.7	6.9
Tilapia	Bio-ring	4.9	4.6	19.3	8.2	28.6	9.4

WG = weight gain, (gm) = grams, L = standard length, (cm) = centimeters

same water could be detoxified using extended aeration. After several hours of aeration, fish were able to live in the water without apparent difficulty. These results prompted further experimentation on the effects of aeration on the toxicity of water used at the Huntington power plant. After this pilot study, two projects were designed and completed to determine multiple use of heated effluent from the power plants.

For project 1, experiments were designed to duplicate previous toxicity testing and to determine long-term fish survival in waste water. The project included short-term (8 day) toxicity using catfish (*Ictalurus punctatus*) and long-term (60 day) toxicity using biological filtration, in which two types of media and two species of fish, catfish and *Tilapia aurea*, were included. The filter media included a high calcium filter medium (bro-

TABLE 3. Growth and survival for long-term toxicity tests. There were 15 catfish and 15 tilapia used in each tank.

Water and animal	Filter system	60-day °WG (gm)	Increase (%)	60-day Mortality (%)
COOLING TOWER WATER				
Tilapia	Oyster shell	314	63	13
Catfish	Oyster shell	650	103	0
Tilapia	Bio-ring	353	94	27
EVAPORATION POND WATER				
Tilapia	Oyster shell	240	64	20
Catfish	Oyster shell	546	103	7
Tilapia	Bio-ring	262	55	27
WASTE WATER				
Tilapia	Oyster shell	150	72	13
Catfish	Oyster shell	688	105	0
Tilapia	Bio-ring	260	70	13
SPRING WATER				
Tilapia	Oyster shell	235	54	0
Catfish	Oyster shell	1050	137	60
Tilapia	Bio-ring	483	104	53

°WG = weight gain, (gm) = grams

TABLE 4. Large-system lower tank (weights, feed, conversions). There were 20 catfish and 20 tilapia used in this tank. Day 1 = 25 Feb 1981.

	Fish weights (g)			Feed (g/Period)		Conversion/Period
Day	Catfish	Tilapia	Total	Duckweed	Commercial	(Feed/Flesh)
1	58.4	182.6	241.0			
14	104.3	265.8	370.1		78.0	0.60:1
30	145.0	400.8	545.8		148.8	0.85:1
45	213.2	619.2	832.4		257.1	0.90:1
60	186.7	590.4	771.1	691.5	–	–
75	178.8	608.5	787.3	1631.0°	–	15.99:1
91	124.0	695.5	819.5	1576.0°	105.4	8.17:1
100	155.9	761.5	917.4	1106.1°	73.8	1.88:1
117	230.5	930.0	1160.5	2201.6°	147.2	1.51:1
132	293.5	1202.0	1495.5	54.0°	273.2	0.83:1

Total gain = 1254.5 g
Total feed – Duckweed = 726.0 g dry wt
Total commercial feed = 1083.5 g
Overall conversion = 1.44:1 (0.58 duckweed/g + 0.86 comm.[)
°Duckweed from an outside source

ken oystershell) and commercial plastic biorings. For the second project a polyculture system, using the same two types of warm water fish, two species of aquatic plants, and a freshwater prawn, was outlined using closed water systems. These organisms were chosen because of their compatibility, high productivity, and marketability (Suffern 1980, Dunseth 1977). An added advantage is that aquatic plants remove nitrogen from the system, helping to maintain good water quality while providing a useful product (Hillman and Culley 1978, Williams 1976).

METHODS AND MATERIALS

Project 1

Fish toxicity trials for Project 1 were conducted using water from the evaporation pond, cooling towers, and neutralizing basin at the Huntington Power Plant and from a freshwater spring located at Brigham Young University. Water from each source was placed in three one-gallon jars. One jar from each water type was included in one of three groups consisting of four jars each. Water in jars of the first group was aerated for 72 hours prior to the addition of fish. Water in the second group was aerated for 24 hours prior to receiving fish. Water in the third group was not aerated and fish were added immediately after the jar was filled. Five fingerling catfish were placed in each jar at the beginning of the study. All jars were then aerated continuously for the eight-day duration of the experiment.

Long-term toxicity testing was conducted using 10-gallon aquaria. Two aquaria were

TABLE 5. Large-system upper tank (weights, feed, conversions). There were 20 catfish and 20 tilapia used in this tank. Day 1 = 25 Feb 1981.

	Fish weights (g)			Feed	Conversion/Period
Day	Catfish	Tilapia	Total	(g/Period)	(Feed/Flesh)
1	48.3	193.9	242.2		
14	75.2	272.6	347.8	79.3	.75:1
30	119.4	377.5	496.9	139.2	.93:1
45	157.8	541.9	699.7	223.2	1.10:1
60	200.7	725.0	925.7	262.5	1.16:1
75	261.0	937.0	1198.0	324.8	1.19:1
91	280.8	976.7	1257.5	420.0	7.06:1
100	319.2	1063.4	1382.6	282.6	2.26:1
117	347.2	1127.5	1474.7	553.6	6.01:1
132	411.0	1308.0	1739.0	479.7	1.81:1

Total gain = 1496.8 g
Total commercial feed = 2764.9 g
Overall conversion – 1.85:1

TABLE 6. Small-system lower tank (weights, feed, conversions). There were 10 catfish and 10 tilapia used in this tank. Day 1 = 25 Feb 1981.

	Fish weights (g)			Feed	Conversion/Period
Day	Catfish	Tilapia	Total	(g/Period)	(Feed/Flesh)
1	28.2	123.4	151.6		
14	42.6	183.8	226.4	79.3	0.66:1
30	45.0	251.7	296.7	91.2	1.30:1
45	62.7	354.1	416.8	133.2	1.11:1
60	93.5	446.8	540.3	156.0	1.26:1
75	10.5	237.0	247.5	165.5	—*
91	16.5	333.7	350.2	93.0	7.06:1
100	20.0	348.1	368.1	79.2	2.26:1
117	39.0	459.0	498.0	147.2	6.01:1
132	42.0	564.0	606.0	162.5	1.81:1

Total gain = 454.4 g
Total commercial feed = 1077.2 g
Overall conversion - 2.37:1 (due to high mortality from day 60–75)
*Mortality due to low D.O. and feeding stress

plumbed together to form one system. Each system consisted of one aquarium acting as a filter while the second acted as a habitat for fish. Twelve systems were divided into three groups consisting of four systems each.

Oystershell was used as a filter medium in two of the three groups, and the remaining group contained plastic bio-rings. Fifteen fingerling catfish were placed in one of the oyster shell groups. Fifteen tilapia were placed in each of the systems in the second oyster shell group. The group using bio-rings received fifteen fingerling tilapia. All fish were weighed and measured (standard length) prior to the beginning of the experiment. The 15 catfish in each tank were weighed as a group because of their small size.

Four water types were used for experimentation within each group. These consisted of water from the cooling tower, evaporation pond, waste water basin of the Huntington Power Plant, and the BYU spring. Water quality parameters of temperature, pH, nitrite, and conductivity were taken weekly.

Project 2

Two closed, recirculating systems were constructed, each involving a sequence of five tanks. Two tanks in each system contained equal numbers of tilapia and channel catfish. The fish in these two tanks were fed a commercial trout diet at the rate of 2.5% of the fish's body weight adjusted at 15-day intervals according to the growth of the fish. For the other tanks, two per system had duckweed (*Lemna minor*) floating on the water surface. One of the duckweed tanks in

TABLE 7. Small-system upper tank (weights, feed, conversions). There were 10 catfish and 10 tilapia used in this tank. Day 1 = 25 Feb 1981.

	Fish weights (g)			Feed	Conversion/Period
Day	Catfish	Tilapia	Total	(g/Period)	(Feed/Flesh)
1	28.5	96.0	124.5		
14	30.0	140.5	170.5	40.3	0.88:1
30	43.1	180.0	223.1	60.8	1.16:1
45	61.0	275.5	336.5	100.8	0.89:1
60	94.0	378.5	472.5	126.0	0.93:1
75	118.0	474.5	592.5	165.2	1.38:1
91	94.3	506.2	600.5	217.0	27.13:1*
100	119.7	536.5	656.2	135.0	2.42:1
117	170.5	603.0	773.5	262.4	2.24:1
132	203.0	717.0	920.0	250.9	1.71:1

Total gain = 795.5 g
Total feed = 1358.4 g
Overall conversion - 1.71:1
*High conversion due to mortality from day 75–91

each system received freshwater shrimp (*Macrobrachium rosenbergii*) and the other received 2 tilapia each. No commercial food was added to the duckweed tanks, leaving the shrimp and tilapia in these tanks to feed on plant growth and waste products coming from the other fish tanks. The fifth tank contained the biological filter that consisted of a crushed oyster shell and the nitrifying bacteria. One filter tank also contained pots of water chestnuts (*Eleocharis dulcis*).

The water flowed through a duckweed tank, a fish tank, the second duckweed tank, the second fish tank, then into the filter. Water from the filter tank was recirculated back into the first duckweed tank. Water quality parameters were measured daily and fish growth was measured every 15 days. Duckweed was harvested as necessary to prevent clogging of pipes and filters and to promote maximum duckweed growth.

In addition to the laboratory system, a cage (4 × 4 × 4 ft, floating, of rubber-coated mesh) was placed in the evaporation pond at the Hunter Power Plant. Fifteen tilapia were placed in the cage and their growth was monitored.

TABLE 8. Duckweed production (Starting 25 Feb 1981) in the large-system upper tank.

Date	Amount harvested (g)
2 April	458.2
20	698.9
12 May	275.0
20	126.0
27	327.0
4 June	286.0
8	129.0
15	135.0
16	135.0
17	135.0
19	135.0
20	135.0
23	44.0
25	102.0
26	45.0
27	57.0
29	45.0
30	110.0
1 July	63.0
2	40.0
6	65.0
Total*	3546.1

*Total = 3546.1 g = 36.7 tons/acre/year.

RESULTS

Project 1

All but two fish used in the short-term toxicity tests survived the eight-day duration of the experiment. The two deaths occurred in evaporation pond water, one in the 72-hour jar and one in the 24-hour jar.

Mortality in the long-term experiments resulted in 10 dead catfish and 6 dead tilapia in the oyster-shell-filtered groups. Eighteen tilapia died in the bio-ring-filtered group. The 10 catfish included one in evaporation pond water and 9 in spring water. The tilapia mortality in the oyster shell group included 2 each in evaporation pond water, waste water, basin water, and cooling tower water. Mortality in the bio-ring system included 4 each in evaporation pond water and cooling tower water, 8 in spring water, and 2 in the water from the waste water basin.

Water quality was acceptable in the oyster shell system during the experimental period; however, nitrite levels in the bio-ring group were well below acceptable levels. Growth data is reported in Tables 2 and 3.

Project 2

Tilapia fed the prepared trout food showed increases in body weight of 10 to 50% every 15 days (Tables 4–7). When fed strictly duckweed at 15% of body weight, the tilapia showed marginal gains but the catfish lost weight (Table 4 between days 45–75). When a mixture of duckweed and trout food was fed, weight gains of up to 28% were achieved (Table 4). The conversion ratios were best

TABLE 9. Duckweed production (Starting 25 Feb 1981) in the small-system upper tank.

Date	Amount harvested (g)
2 April	317.1
22	266.0
12 May	319.5
23	170.0
30	192.0
2 June	142.0
13	140.0
21	70.0
Total*	1616.6

*Total = 1616.6 g = 38.9 tons/acre/year.

when duckweed and commercial feed were used together (Table 4). The tilapia and shrimp in the duckweed tanks grew rapidly without being fed any outside food, eating only the existing plant growth and waste products. Duckweed production has been measured at approximately 33 tons/ac/yr (Tables 8–10). Duckweed in the large-system lower tank did not have a chance to reproduce before the fish in the tank ate it. The small system that had contained the power plant evaporation pond water since day 77 (Tables 11 and 12) experienced a spawning on day 117 in the lower fish tank. The newly hatched fish were removed from the fish tank and placed in the duckweed tanks. As of August they were nearly 1.5 inches long, feeding entirely on duckweed and waste products in the system. Some mortality of fish was experienced due to low dissolved oxygen (D.O.) at times. The low dissolved oxygen was probably due to the high respiration from plant materials growing in the system and the biologic filter organisms. To compensate for the problem, air stones were added.

The water chestnuts grew poorly under the normal fluorescent lights but did well under the broad spectrum lights. At the Hegerhorst system in Benjamin, Utah, water chestnuts from the same stock, planted outside at the same time, grew to approximately 5 feet tall and have been harvested.

It can be seen that the large system reacted the same as the small system, but not as quickly. The biological filters required a normal period of time to establish themselves, as shown by the nitrite levels, but were sufficient to handle 2.5% feed rates.

TABLE 10. Duckweed production (Starting 25 Feb 1981) in the small-system lower tank. Two fish were included in this tank.

Date	Amount harvested (g)
2 April	250.8
22	139.7
21 May	203.0
8 June	121.0
14	138.0
21	70.0
24	54.0
Total°	975.7

°Total = 975.7 g = 23.4 tons/acre/year.

The evaporation pond at Hunter during July and August 1981 contained mayflies, dragonflies, damselflies, numerous water beetles, and abundant vegetation. The fish in the cage were given no food except for some of the mosses and aquatic insects that existed in the pond. The fish grew very well on the natural productivity of the pond, increasing 64% in weight in one month (Table 13).

DISCUSSION

Results from short-term and long-term tests indicate that all the waters used in this experiment were acceptable for growing both species of fish under the defined conditions. Animal growth was considered to be satisfactory in all systems. The high mortality rate in the spring water aquaria was probably due to contamination of the water line, because the spring water pumps were being repaired the day prior to beginning the experiments.

The results of the short-term toxicity testing were surprising because there was much less mortality than was expected. It appeared that none of the water sources contained the substances that had produced toxicity in the past. One possible explanation for this lack of toxicity might be that the toxin or toxins are not continuously present in the waste waters from the power plant. Therefore, the toxin may be the result of some variation in the normal processes of the power plant.

Discussion with personnel at the power plant indicated that periodically the blowdown from the SO_2 scrubbers have been released into the evaporation pond. It was also found that changes have been made to prevent this from occurring in the future. It appeared likely that this blowdown may have been the source of the periodic toxicity observed in the evaporation pond. Examination of fish tissue using EDAX (Energy Dispersive

TABLE 11. Water quality for large system.

Parameter	Mean	Range
Temperature (centigrade)	26.8	23.0–31.0
pH	7.7	7.4–8.5
Conductivity	535	250–800
Oxygen (ppm)	3.95	1.62–7.2

Analysis for X-Rays) in conjunction with SEM (Scanning Electron Microscopy) indicated high levels of sulfur that further confirmed this hypothesis. The EDAX technique can detect elements found in tissue in ppm and ppb.

The advantages and potential of this type of aquaculture system are great. The present data indicate that the closed, recirculating polyculture system will operate efficiently, especially when duckweed from within the system is used as a supplemental feed. This corroborates other findings (Mayo 1976, Ray 1981, Siddal 1974). It is reported that 75–80 percent of the production costs in aquaculture come from the feed and fingerlings (USDA Economic and Statistical Service 1981). Duckweed as a supplement could be an important factor in cutting back these costs. The economic values of a polyculture system are obvious because there is more production per unit of culture. Our tests have also shown that there is no apparent effect upon the organisms using waste waters from Utah Power and Light's Hunter Unit, and, thus, on the basis of our tests, it appears that the water can be used directly in the aquaculture system. Although this system will produce a protein source suitable for human consumption, it will also produce other benefits that have been summarized below:

1. The system will provide a secondary method for the consumption of waste heat, drawing required amounts of heat directly from water lines carrying waste heat to the cooling towers.
2. This system could allow additional use of heat and water from geothermal projects prior to water reinjection.
3. Water flowing from aquaculture operations will carry nutrients beneficial to surface farming operations.
4. The aquaculture operations are nonconsumptive. Water losses will be limited to evaporation.
5. Duckweed production from aquaculture ponds can be used as a protein supplement for cattle. Up to 75% replacement of cattle feed by duckweed has been tested successfully by other researchers (Hillman and Culley 1978).

TABLE 12. Water quality for small system.

Parameter	Mean	Range
Temperature (centigrade)	27.2	25.0–30.0
pH	7.7	7.2–8.4
Conductivity	510/4930°	440–600/2900–7000
Oxygen (ppm)	5.14	1.26–7.80

°Higher conductivity levels are the result of the change from spring water to evaporation pond water.

LITERATURE CITED

DUNSETH, D. R. 1977. Polyculture of channel catfish (*Ictalurus punctatus*), silver carp (*Hypophthalmichthys molitrix*), and three all male tilapias (*Sarotherodon* spp.). Unpublished dissertation. Auburn Univ. 62 pp.

HILLMAN, W. S., AND D. D. CULLEY, JR. 1978. The uses of duckweed. Amer. Scientist 66:442–451.

HOLDEN, C. 1978. Government seeking ways to encourage aquaculture. Science 200:33–35.

MAYO, R. D. 1976. A technical and economic review of the use of reconditioned water in aquaculture. Aquaculture 1976:508–520.

RAY, L. 1981. Channel catfish and tilapia production in geothermal water. Paper given at the Annual Meetings of the Soil Conservation Society of America, 2–5 August, Spokane, Washington.

RINEHART, J. S. 1980. Geysers and geothermal energy. Springer Verlag, Berlin.

SIDDAL, J. 1974. Studies of closed marine culture systems. Prog. Fish Cult. 36(1):8–15.

TABLE 13. Cage culture at the Hunter Power Plant in 1981.

20 July		15 August	
Length (mm)	Weight (g)	Length (mm)	Weight (g)
175	91	128	37
128	37	147	52
170	82	176	102
134	38	183	117
175	100	184	112
156	65	125	43
114	24	140	58
123	31	151	76
144	48	147	69
125	31	133	46
120	24	150	75
130	31	152	73
132	38	154	76
113	19	152	84
135	39		

20 July 1981
Mean length = 138.3 mm   Mean Wt. = 46.5 g
Range = 113 – 175 mm   Range = 19 – 100 g
Std Dev = 21.2   Std Dev = 25.7

15 August 1981
Mean length = 151.6 mm   Mean Wt. = 72.9 g
Range = 125 – 184 mm   Range = 37 –c117 g
Std Dev = 18.5   Std Dev = 24.9
Increase = 38%   Increase = 64%

SUFFERN, J. S. 1980. The potential of tilapia in U.S. aquaculture. Aquaculture 6:14–18.

U.S. DEPARTMENT OF AGRICULTURE, ECONOMICS AND STATISTICS SERVICE. 1981. Aquaculture outlook and situation report. U.S. Government Printing Office, Washington, D.C.

WILLIAMS, A. K. 1976. Chinese water chestnut culture. *In* Horticultural crops. Richard B. Russell Agricultural Research Center, Athens, Georgia.